Potato Response to Phosphorus Fertilizer Using a Dicarboxylic Acid Polymer

By Jeffrey C. Stark and Bryan G. Hopkins

Improving P use efficiency in some alkaline soils is difficult due to poor P solubility. A dicarboxylic acid polymer (DCAP) was added to P fertilizer to improve potato P uptake, efficiency, and yield. This five-year study consisting of nine field trials, evaluated potato response to seasonal applications of liquid or dry P fertilizer with or without DCAP on calcareous soils with low to moderate soil test P. Addition of DCAP increased total yields of premium quality "U.S. No. 1" potatoes for selected P rate/source/timing combinations in seven of the nine trials.

Maintaining an adequate P supply is critical for potato plant development, tuber growth, and enhancing tuber maturity. Phosphorus deficiencies can significantly reduce tuber yield and size. Therefore, fertilization practices must be customized for the characteristics of the cropping system and local conditions to maintain adequate P availability throughout the growing season. Concentrations of soluble P in soils of the potato-producing regions in the Pacific Northwest, USA are usually very low and must be constantly replenished from soil P sources during the growing season.

In these alkaline soils, the primary factors used in determining P fertilizer recommendations are soil test P concentration, amount of excess lime ($CaCO_3$), and the yield goal. Excess lime in the soil increases P sorption on $CaCO_3$ surfaces and increases P precipitation as Ca-P minerals. The combined effect of these processes is an overall reduction in P availability to plants. This is reflected in regional potato P fertilizer recommendations that adjust for excess lime content in soil.

In this region, P fertilizer for potato is typically added in the fall or in the spring as a broadcast application, as a concentrated band during bed formation, and/or as a concentrated subsurface band at planting. The effectiveness of banded P for potato has been shown to vary with P source in calcareous soil; with the acidity of the fertilizer solution being a key factor. Banding P fertilizer in the soil can be beneficial by concentrating P near the early-developing root system.

One approach to improving P use efficiency is to reduce the concentration of potentially reactive cations in the immediate vicinity of the P fertilizer when applied to the soil. A long-chain dicarboxylic acid (DCAP) copolymer (AVAIL®; SFP, Leawood, KS, USA) composed of maleic and itaconic acids has been developed to improve crop P uptake efficiency (**Figure 1**). It is highly water soluble and only slightly mobile in the soil. A coating of DCAP on monoammonium phosphate (MAP)

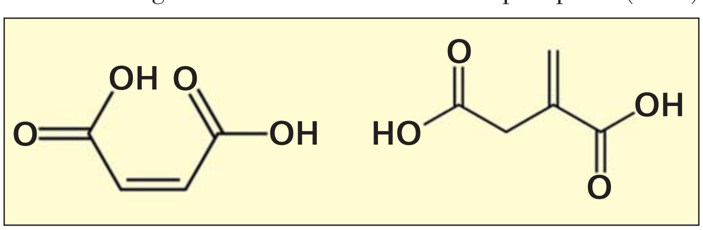

Figure 1. The dicarboxylic acid polymer is composed of a long chain of maleic acid (left) and itaconic acid (right). A dicarboxylic acid is an organic compound that contains two carboxylic acid functional groups.

Abbreviations and Notes: P = phosphorus; Ca = calcium; Mg = magnesium; v/v = volume-to-volume; ton/A = tonnes/ha x 0.446.

Daily potato P uptake requirements typically range from 0.7 to 1.8 kg P_2O_5/ha/day during the tuber-bulking phase.

fertilizer may significantly modify soil chemical characteristics in the immediate vicinity of a fertilizer granule and thereby improve P uptake and crop yield. DCAP is also formulated for inclusion in liquid P fertilizers.

The DCAP coating is reported to provide a high negative-charge density compound that dissolves rapidly in the soil. The benefit would occur when the polymer sequesters soil cations (such as Ca, Mg), thereby increasing P solubility and making P more accessible for plant uptake. There are multiple reports where DCAP has shown significant yield benefits for a variety of crops. However, there also are multiple reports where no yield benefit has been obtained from use of DCAP-treated P fertilizer compared with untreated P. The specific conditions where benefits from DCAP should be expected are still under investigation.

The objective of this study was to evaluate potato yield response to DCAP applied in the fall and spring with both dry and liquid P fertilizer on calcareous soils considered "low to moderate" in soil P concentrations for potato production. Optimum recommended soil P concentrations are higher for potatoes than for many other agronomic crops.

A total of nine irrigated field trials were conducted in southeastern Idaho, USA between 2004 and 2008. Additional experimental details are available in Hopkins (2013) and Stark and Hopkins (2013). All of the trials were conducted with the Russet Burbank potato cultivar and all were conducted on calcareous soils with pH values ranging from 7.8 to 8.3 and excess lime contents ranging from 1.0 to 9.7% (**Table 1**).

Table 1. Selected soil parameters for the nine potato P fertilization trials

Trial	Year	Soil Type	pH	Organic matter, %	$CaCO_3$, %	Extractable[1] soil P, mg/kg
1	2004	Sandy loam	8.0	2.1	1.0	35
2	2004	Loam	7.9	1.9	5.4	19
3	2004	Loam	8.0	1.7	3.4	18
4	2004	Sandy loam	8.1	2.4	2.9	21
5	2005	Loam	7.8	2.9	1.5	30
6	2005	Sandy loam	8.1	1.7	5.6	19
7	2006	Loam	8.1	2.8	9.7	17
8	2007	Sandy loam	8.1	1.9	6.8	18
9	2008	Sandy loam	8.3	2.1	7.2	21

[1]Olsen-P

Trials 1 through 5 (2004-2005)

The first five trials listed in **Table 1** were conducted in grower fields near the University of Idaho Research and Extension Center Aberdeen, Idaho in 2004 and 2005. Individual plot sizes were 3.6 m wide (four 0.9 m width rows) by 12 m long with 30 cm in-row seed piece spacing. Six replicates of three treatments were established in randomized complete blocks (RCBD) in each field. Treatments included an untreated check (no P fertilizer) or 67 kg P_2O_5/ha of MAP fertilizer applied with or without addition of DCAP at 1% (w/v).

The fertilizer was broadcast applied within 0 to 3 days prior to planting and incorporated with routine tillage operations. The P application rate selected was based on soil sampling to a depth of 25 cm and represented a slight excess above University of Idaho recommendations. Nitrogen was balanced in all plots with application of broadcast urea fertilizer at the same time as the pre-plant P treatments were applied. At harvest, tubers were harvested, graded, and weighed to determine total and U.S. No. 1 yield, which reflects the premium tuber quality that commands the highest market prices.

Three of the five trial sites showed significant ($p \leq 0.07$) increases in total yield in response to P fertilization (**Table 2**).

Table 2. Total and U.S. No. 1 yields of Russet Burbank potato for trials 1 through 5 as influenced by P applied as MAP or DCAP-treated MAP.

Fertilizer	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
---------- Total yield, t/ha ----------					
Check	44.0	35.5	27.6	28.4	39.6
MAP	45.8	39.1	30.4	36.7	40.8
DCAP	35.5	43.5	34.3	42.3	44.8
$LSD_{0.10}$	5.3	3.5	3.7	5.3	NS
Pr > F	0.018	0.045	0.067	0.017	0.103
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
---------- U.S. No. 1 yield, t/ha ----------					
Check	30.3	21.9	16.8	17.6	23.1
MAP	31.6	26.7	17.6	21.9	23.7
DCAP	17.3	30.7	19.1	23.8	25.1
$LSD_{0.10}$	4.5	3.8	NS	5.8	NS
Pr > F	0.012	0.033	0.218	0.038	0.246

Addition of MAP resulted in significant total yield increases over the untreated check in trials 2 and 4 but DCAP reduced total yield in trial 1, where initial soil P was relatively high. U.S. No. 1 yields were increased by P fertilization only in trial 2. The lack of response to MAP in the other trials is not surprising since these fields had relatively high soil test P concentrations. It is interesting that the two fields that responded positively to MAP fertilization were on the lower end of soil test P concentrations of the five fields used in this study (**Table 1**). Both trials that responded to MAP fertilizer (trials 2 and 4) also responded with additional yield increases when DCAP was combined with the MAP fertilizer. Although there was no response to MAP without DCAP compared to the check for trial 3, the MAP+DCAP-treated plots increased total yield over both MAP alone and the untreated check plots.

Significant differences ($p \leq 0.05$) for U.S. No. 1 yield were observed in trials 1, 2 and 4 (**Table 2**). As with total yield, the U.S. No. 1 yield in trial 2 for the MAP+DCAP-treated plots was significantly greater than MAP-treated plots. Trial 4 also had a similar response where MAP+DCAP resulted in a significant U.S. No. 1 yield increase compared to the untreated check but not compared to MAP alone. Petiole P concentration of MAP+DCAP-treated plants was significantly greater than the other treatments at mid and late season sampling dates for trials 1-5 (data not shown).

Trials 6 through 9 (2005-2008)

Trials 6, 8 and 9 were conducted at the University of Idaho Aberdeen Research and Extension Center, while trial 7 was conducted in a grower's field near Blackfoot, ID. Individual plot sizes in these trials were 3.6 m wide (four 0.9 m width rows) by 15 to 18 m long with 30 cm in-row seed piece spacing. Treatments for trials 6 and 7 included an untreated check (no P fertilizer) and different rates of MAP fertilizer applied +/- DCAP at 1% (w/v). Treatments for trials 8 and 9 also included an untreated check and different rates of MAP +/-DCAP (1% w/v) or ammonium polyphosphate (APP) applied +/-DCAP at 0.5% (v/v).

All nutrients besides P, were applied to provide for optimum yield based on soil tests taken the previous fall. Nitrogen was balanced in all plots with application of broadcast urea at the same time as the pre-plant P treatments were applied. Irrigation water was added as needed. At maturity, tubers were harvested, graded, and weighed to determine total and U.S. No. 1 yield.

Experimental designs for the trials 6 and 7 were arranged as a split plot, RCB design with fall or spring P application as the main plots and P source/rate combinations as subplots with four replications. The P rates were 0, 112 or 224 kg P_2O_5/ha.

The experimental design for trial 8 was similar to trials 6 and 7 with the exception that spring P was banded rather than broadcast applied. The P treatments included fall plus spring applications of P (0, 180 or 270 kg P_2O_5/ha), compared with single spring P applications (0, 180 or 270 kg P_2O_5/ha) applied entirely as band treatments of APP +/- DCAP. The split, fall plus spring applications were comprised of fall broadcast MAP +/- DCAP applied at 90 or 180 kg P_2O_5/ha plus 90 kg P_2O_5/ha as APP banded in the spring, +/-DCAP. A control treatment (check) received no additional P. APP treatments were banded at row formation 15 to 20 cm below the surface of the hill and

Table 3. Total and U.S. No. 1 yields of Russet Burbank potato for trials 6 and 7 as influenced by P applied in the fall or spring as MAP or MAP treated with DCAP.

Fertilizer	Fall P	Spring P	Trial 6 Total yield	Trial 6 U.S. No. 1	Trial 7 Total yield	Trial 7 U.S. No. 1
	- - kg P_2O_5/ha - -		- - - t/ha - - -			
Check	0	0	37.9	23.7	44.9	31.3
MAP	112	0	43.0	30.0	45.8	31.5
DCAP	112	0	44.1	28.1	50.5	37.6
MAP	224	0	43.9	28.8	48.3	35.6
DCAP	224	0	44.2	32.5	50.0	38.4
Check	0	0	38.9	20.8	44.8	31.5
MAP	0	112	39.9	24.3	45.6	31.7
DCAP	0	112	43.1	29.2	49.1	36.7
MAP	0	224	42.2	24.3	46.8	31.9
DCAP	0	224	42.8	24.5	46.4	34.6
Treatment Means						
MAP			42.3	26.8	46.6	32.7
DCAP			43.6	28.6	49.0	36.8
Fall			43.8	29.9	48.7	35.8
Spring			42.0	25.6	47.0	33.7
$LSD_{0.05}$			ns	2.8	1.8	2.8
PR > F			0.093	0.052	0.001	0.001

9 to 10 cm to the side of the seed row.

In trial 9, the treatments included comparisons of P applied entirely in the spring at 0, 90, 180 or 270 kg P_2O_5/ha; with the P treatments consisting of 45 or 90 kg P_2O_5/ha broadcast as MAP, +/-DCAP, and the remainder applied as APP, +/- DCAP, banded in the bed prior to planting, as previously described.

Total potato yields were significantly increased in trial 6 where P was added ($p \leq 0.10$). The mean total yield for the P-fertilized treatments (42.9 t/ha) was higher than the mean check yield (38.4 t/ha) but there were no significant differences in total yield between any of the P source/rate/DCAP treatment combinations (**Table 3**).

There was a significant yield increase ($p \leq 0.05$) for U.S. No. 1 tubers in response to P treatment in trial 6. All P-fertilized treatments had higher U.S. No. 1 yields than the check for both fall and spring fertilization. DCAP treatment resulted in significantly more U.S. No. 1 potatoes when added to fall-applied MAP at 224 kg P_2O_5/ha and to spring-applied MAP at 112 kg P_2O_5/ha than uncoated MAP at those same rates. However, DCAP had no effect on U.S. No. 1 yield for the other P rate/timing combinations. In addition, fall P fertilization produced higher U.S. No. 1 yields than spring P fertilization.

In trial 7, DCAP treatment resulted in significantly ($p \leq 0.05$) higher total and U.S. No. 1 yields than MAP without DCAP. The benefit of DCAP on each of these yield parameters were greatest at the lower P rate (112 kg P_2O_5/ha), particularly with respect to total yield. The use of DCAP resulted in higher U.S. No. 1 yields for all P rate/timing combinations, except for the spring-applied treatment at 224 kg P_2O_5/ha where there was no benefit.

In trial 8, main effects of DCAP addition were not significant for total or U.S. No. 1 yield (**Table 4**). However, there were significant effects of P application on total and U.S. No. 1 yield and for DCAP on total yield for selected P rate/source/timing treatment combinations. For example, at the 180 kg P_2O_5/ha application rate, fall + spring P application plus DCAP produced a higher total yield than fall + spring application without DCAP. Conversely, at the 270 kg P_2O_5/ha rate, total yield for the fall + spring treatment with DCAP was lower than the fall + spring treatment without DCAP.

Trial 9 focused entirely on potato response to spring-applied P, with the applications evenly split between broadcast MAP and banded APP applied +/- DCAP. At each P application rate, the addition of DCAP produced significant increases in U.S. No. 1 tuber yield, ranging from 18 to 26% compared to untreated MAP and APP. Total yields exhibited a similar trend, but treatment effects were not significant (**Table 5**).

Petiole P concentration of MAP+DCAP-treated plants in trials 1-5 was significantly greater ($p \leq 0.10$) than the other treatments at mid and late season sampling dates at all sites (**Figure 2**). However, plant P analysis for trials 6-9 revealed no significant ($p \leq 0.05$) differences in stem, tuber or total plant P uptake between the P-source or the P-timing treatments, nor were there significant differences in petiole P concentrations among treatments (data not shown).

Summary

In summary, DCAP increased total and/or U.S. No. 1 yields for selected P rate/source/timing combinations in 7 of 9 trials.

Table 4. Total and U.S. No. 1 yield of Russet Burbank potato for trial 8 as influenced by P applied in the fall and spring as MAP or APP applied with or without DCAP.

Fertilizer	Fall P, kg P_2O_5/ha	Spring P, kg P_2O_5/ha	DCAP	Total P, kg P_2O_5/ha	Total yield, t/ha	U.S. No. 1, t/ha
Check	0	0	0	0	44.3	25.7
MAP/APP	90	90	0	180	45.7	26.0
MAP/APP	90	90	+DCAP	180	49.7	26.6
MAP/APP	180	90	0	270	51.9	30.5
MAP/APP	180	90	+DCAP	270	47.7	26.6
Check	0	0	0	0	45.1	24.2
APP	0	180	0	180	48.1	29.8
APP	0	180	+DCAP	180	50.4	29.9
APP	0	270	0	270	50.1	31.3
APP	0	270	+ DCAP	270	48.2	29.3
Treatment Means						
- DCAP					49.0	29.4
+ DCAP					49.0	28.1
Fall/Spring					48.8	27.4
Spring					49.2	30.1
$LSD_{0.05}$					3.9	5.1
PR > F					0.003	0.050

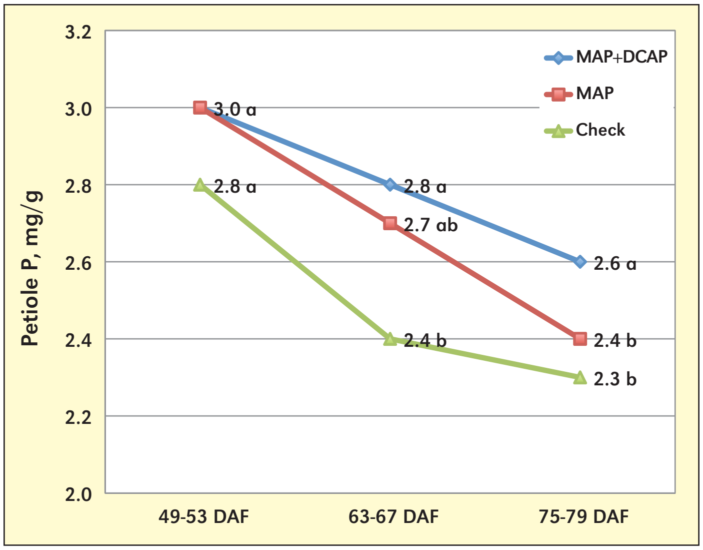

Figure 2. Petiole P concentrations for potatoes grown without fertilizer P (check), with untreated MAP, or dicarboxylic acid polymer (DCAP)-treated MAP. Data are combined for trials 1-5. DAF = days after fertilization. Data points with the same letter at a specific DAF are not significantly different at $p \leq 0.10$.

Not surprisingly, these results show that the benefit of DCAP-treated fertilizer is more likely when soil test P concentrations are low and at modest rates of fertilizer P. Evidence from these trials and the work of other researchers suggest that high rates of P overwhelm any beneficial response from DCAP.

It is clear from the range of responses reported by various researchers that many factors, including crop type, soil properties, fertilizer source, rate, placement, timing, etc., can have effects on crop response to P fertilizers blended with DCAP. However, the growing number of positive yield responses to DCAP observed for such crops as potato, rice and maize suggest that further research with this product is warranted to improve its effectiveness and the predictability of response.

Table 5. Total and U.S. No. 1 yield of Russet Burbank potato for trial 9 as influenced by P applied in the spring as MAP or APP applied with or without DCAP.

Total P, kg P_2O_5/ha	MAP, kg P_2O_5/ha	APP, kg P_2O_5/ha	DCAP	Total yield, t/ha	U.S. No. 1, t/ha
Check	0	0	0	40.4	21.8
90	45	45	0	44.1	22.3
90	45	45	+DCAP	43.6	28.2
180	90	90	0	41.8	22.5
180	90	90	+DCAP	50.0	26.6
270	90	180	0	43.1	25.2
270	90	180	+DCAP	45.6	29.8
Treatment Means					
Fertilizer P without DCAP			43.0	23.3	
Fertilizer P with DCAP			46.4	28.2	
$LSD_{0.05}$				ns	4.1
PR > F				0.37	0.05

Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product by the authors or IPNI.

Dr. Stark is a Professor, Department of Plant, Soil, and Entomological Sciences, University of Idaho; e-mail: jstark@uidaho.edu. Dr. Hopkins is a Professor, Plant and Wildlife Sciences Department, Brigham Young University; e-mail: hopkins@byu.edu.

References

Hopkins, B.G. 2013. J Plant Nutrition. 36:1287-1306.
Stark, J.C., and B.G. Hopkins. 2013. J Plant Nutrition (accepted for publication Sept. 25, 2012).

IPNI Crop Nutrient Deficiency Image Collection – Now Multilingual

A recent update to IPNI's full collection of crop nutrient deficiencies has resulted in the translation of this highly successful resource into four additional languages including: French, Portuguese, Russian, and Mandarin.

You'll find more than 530 images representing over 70 crops. Images are grouped according to primary, secondary, and micronutrient categories and search results can be filtered by crop for quick access. Multilingual text and diagrammatic descriptions of each example of nutrient deficiency are available as supporting information.

For more details see: http://info.ipni.net/NutrientImageCollection